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Research Note

Effect of Exposure Duration on Spatial Uncertainty in Normal and Amblyopic Eyes

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Previous studies have found that the spatial uncertainty of amblyopes is critically dependent on temporal factors. These studies claim that the spatial uncertainty is much greater at short exposure durations. We have reassessed the effect of exposure duration on the spatial uncertainty of normal and amblyopic eyes using a task in which we can compensate for the loss in contrast sensitivity which inevitably occurs as exposure duration is shortened. Our task involved a three-element alignment task, where each of the elements were spatial Gabors at two different separations. We ensured that our stimuli were always displayed at a fixed ratio above contrast detection thresholds at each exposure duration. Our results show that for normal subjects, for well separated equi-visible stimuli, there is only a weak effect of exposure duration. A similar dependence is found for the dominant and amblyopic eyes of a group of strabismic amblyopes. Dominant eyes of strabismic amblyopes show increased spatial uncertainty compared with normal subjects. Amblyopic eyes of strabismic amblyopes show increased spatial uncertainty compared with their dominant fellow eye which is invariant with exposure duration. Some subjects show a larger positional deficit at short durations when the stimuli are almost abutting.

Amblyopia   Spatial uncertainty   Contrast sensitivity   Exposure duration

INTRODUCTION

Rentschler and Hilz (1985) as well as Weiss *et al.* (1985) have shown that vernier acuity and phase discrimination deficits are critically dependent on exposure duration for the amblyopic eye of strabismic amblyopes. Indeed at an exposure duration of 50 msec they were unable to measure amblyopic thresholds. It is therefore of some importance to understand why the spatial uncertainty in amblyopic eyes has such a strong temporal dependence.

Normal subjects exhibit virtually no dependence on exposure duration for alignment thresholds if the visibility of the stimuli at different exposure durations is accounted for. Hadani *et al.* (1984) demonstrated this using a three-dot alignment task for a constant energy condition as did Waugh and Levi (1993) for equi-visible abutting sinusoidal gratings. The need to control for the changing visibility of stimuli which occurs as a consequence of displaying them at different exposure durations is of paramount importance in amblyopia where there are believed to be deficits for both contrast and positional sensitivity (Hess & Holliday, 1992; Levi *et al.*, 1994). Furthermore, there is evidence that the contrast sensitivity deficit in amblyopia does vary with exposure duration, especially in the high spatial frequency range (Loshin & Jones, 1982). Therefore, any comparisons between alignment thresholds for amblyopic and dominant eyes should ensure that the stimuli used are equally visible to both eyes at all exposure durations. One convenient method of achieving this is to use spatially narrowband elements in the alignment task and to measure their individual contrast detection thresholds at different exposure durations. Spatial uncertainty can then be measured with stimulus elements presented at a constant fraction above their individual contrast thresholds. To assess the claim that spatial uncertainty in amblyopia is critically dependent on exposure duration, we used such a procedure in a group of normals and strabismic amblyopes. We used stimuli whose elements were either well separated or almost abutting.

The results demonstrate that normal subjects' alignment performance, for equi-visible stimuli, shows only slight improvements with increased exposure duration.

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TABLE 1. Clinical data for the strabismic amblyopic subjects

Subject	Age	Sex	Eye	Refraction	Acuity	Fixation	Ocular alignment	History
OA (strab/aniso)	18	M	RE	− 4.50/− 5.00 × 030	6/24	3 deg nasal	5 deg RET	Diagnosed age 3 yr, Rx age 3 yr, patching age 3 yr, no surgery
			LE	− 1.75/− 1.75 × 150	6/6	Centred		
MG (strab)	17	F	RE	+1.75	6/30	2 deg nasal	10 deg LET	Diagnosed age 5 yr, patching age 5 yr, no surgery
			LE	+1.50	6/6	Centred		
MS (strab)	24	F	RE	+0.75	6/6	Centred	10 deg LET	Amblyopia age 9 yr, Rx age 9–20 yr, no patching, no surgery
			LE	+1.00	6/18	1 deg nasal/inf		
HC (strab)	21	F	RE	+5.25	6/4.5	Centred	5 deg LET	LET age 1 yr, patched sporadically 2–5 yr, Rx since age 3 yr, no surgery
			LE	+5.25	6/7.5	0.5 deg nasal		
VE (strab/aniso)	65	M	RE	+0.75	6/6 + 2	Centred	6 deg LXT	LXT diagnosed age 7 yr, Rx since age 7 yr, no patching, no surgery
			LE	+3.00	6/24	Centred		
CC (strab)	23	M	RE	+1.00	6/12	Centred	6 deg RET	RET diagnosed at age 3 yr, patching and visual training age 5 for 1 yr, first Rx age 5 yr, no surgery
			LE	+1.00	6/4.5	Centred		

RE, right eye; LE, left eye; ET, esotropia; XT, exotropia

The amblyopic and dominant fellow eyes show a similar dependence on exposure duration, thus spatial uncertainty when measured with well separated equi-visible stimuli, is invariant with exposure duration in strabismic amblyopia. This is also true for results obtained for more closely spaced stimuli, however under these conditions there are at least some strabismic subjects who may exhibit larger positional deficits at short exposure durations.

METHODS

Alignment performance was assessed for three normal subjects (the authors and one naive subject) and for the amblyopic and fellow dominant eyes of six strabismic amblyopes. Clinical details are provided in Table 1.

The two-alternative forced-choice task consisted of determining the position (left or right) of the central element compared to the two outer vertically aligned Gabors. From the resulting psychometric function, the alignment threshold was found by fitting the error function. The stimulus and measurement details for spatial alignment and contrast threshold determination are given in more detail elsewhere (Hess & Holliday, 1992). At least two estimates were obtained in all cases, each consisting of 220 trials. Contrast detection thresholds were independently determined for the central and the two outer reference Gabors and fixed to 8 dB (a factor of 2.5) above this value in the assessment of alignment performance. The carrier frequency of the Gabors was in cosine phase and vertically oriented. The viewing distance was 2 m (1 m for amblyopic subjects OA and VE) and represented the furthest distance possible such that all stimuli could be presented at 8 dB above their

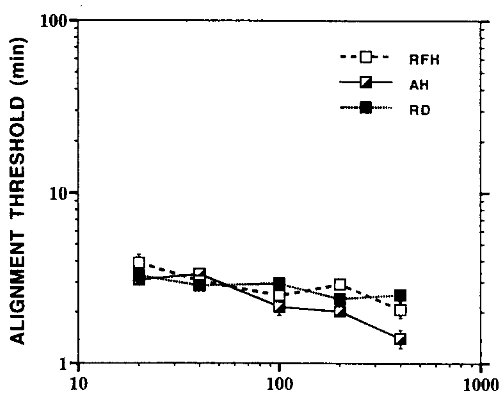

FIGURE 1. Alignment thresholds as a function of exposure duration, plotted as the spread (1/e half width) of the Gaussian temporal envelope of the stimuli in msec, for three normal subjects. Spatial separation between stimulus elements is 5 × σ (standard deviation of spatial Gaussian). Error bars indicate the SEM and are at times smaller than the symbol sizes.

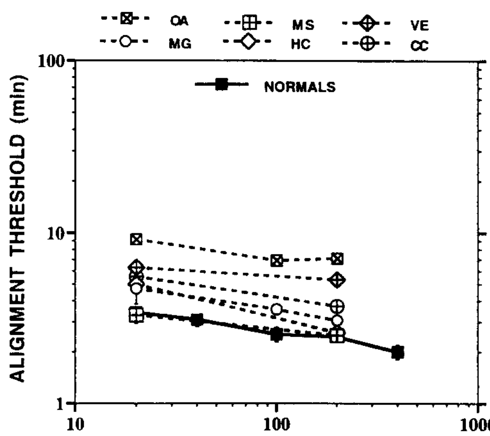

FIGURE 2. Alignment thresholds as a function of exposure duration, plotted as the spread of the Gaussian temporal envelope of the stimuli in msec, for the averaged normal data shown in Fig. 1 (■) and the dominant eyes of the six strabismic amblyopes tested (open and crossed symbols). Error bars indicate the SEM and are at times smaller than the symbol sizes.

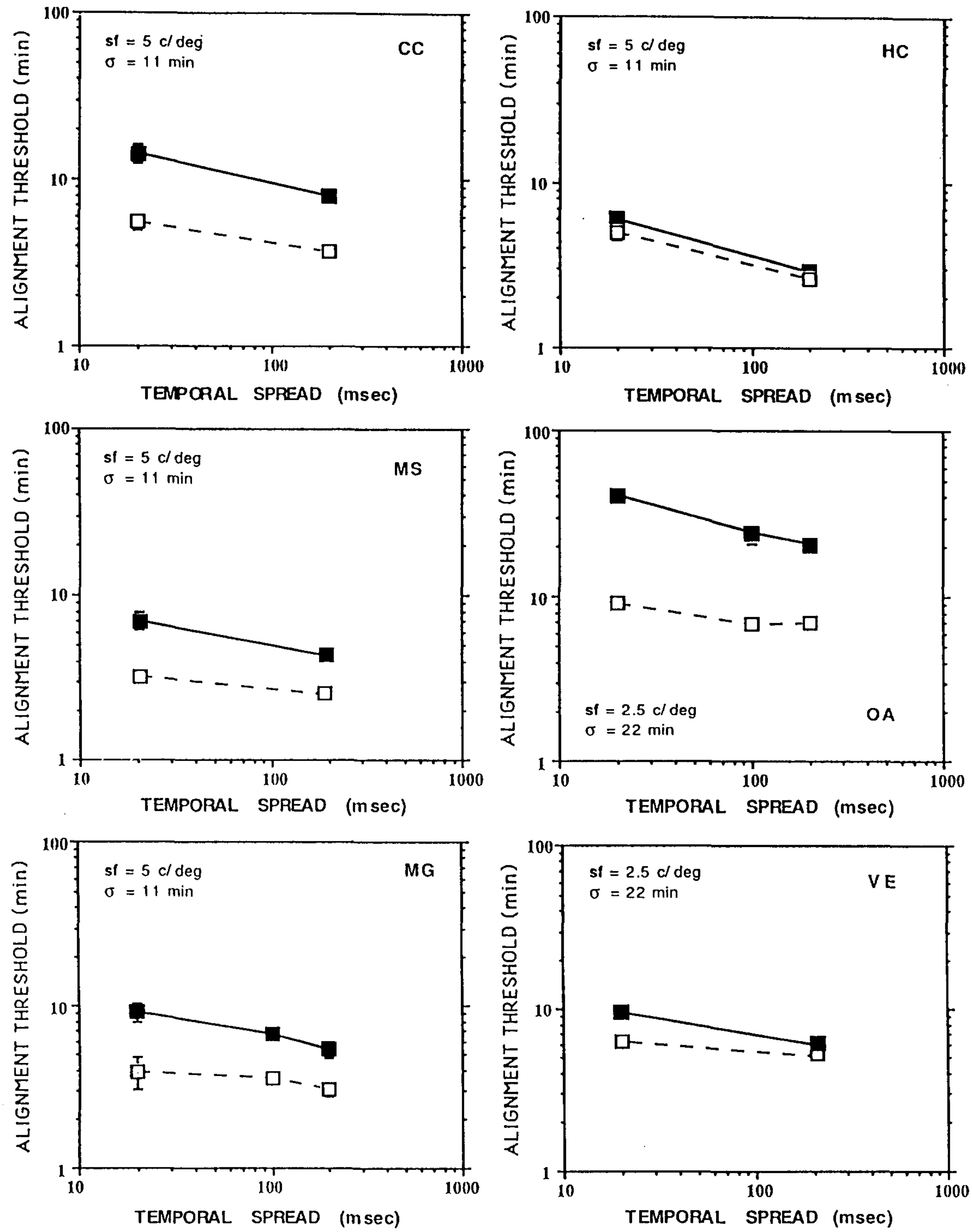

FIGURE 3. Alignment thresholds as a function of exposure duration, plotted as the spread of the Gaussian temporal envelope of the stimuli in msec, for the amblyopic (■) and fellow dominant eyes (□) of the six strabismic subjects tested. The spatial properties of the stimuli such as the spatial frequency of the carrier (sf) and standard deviation (σ) of the Gaussian *spatial* envelope are specified. Stimulus element separation is $5 \times \sigma$. Error bars indicate the SEM and are at times smaller than the symbol sizes.

individual contrast thresholds. At 2 m the Gabors had a Gaussian standard deviation (σ) of 11 min arc and a peak spatial frequency of 5 c/deg and were spatially separated from each other by either 5 or 2.5 times σ (i.e., 55 or 27.5 min arc). The exposure duration of the stimulus, presented on the display screen (Joyce Electronics: mean luminance, 300 cd/m^2; frame rate, 100 Hz), was varied by using a Gaussian temporal envelope with a spread, defined as the time for the function to decrease to 1/e of its initial value, of 20, 40, 100, 200 and 400 msec.

RESULTS

Figure 1 shows the results of the effect of exposure

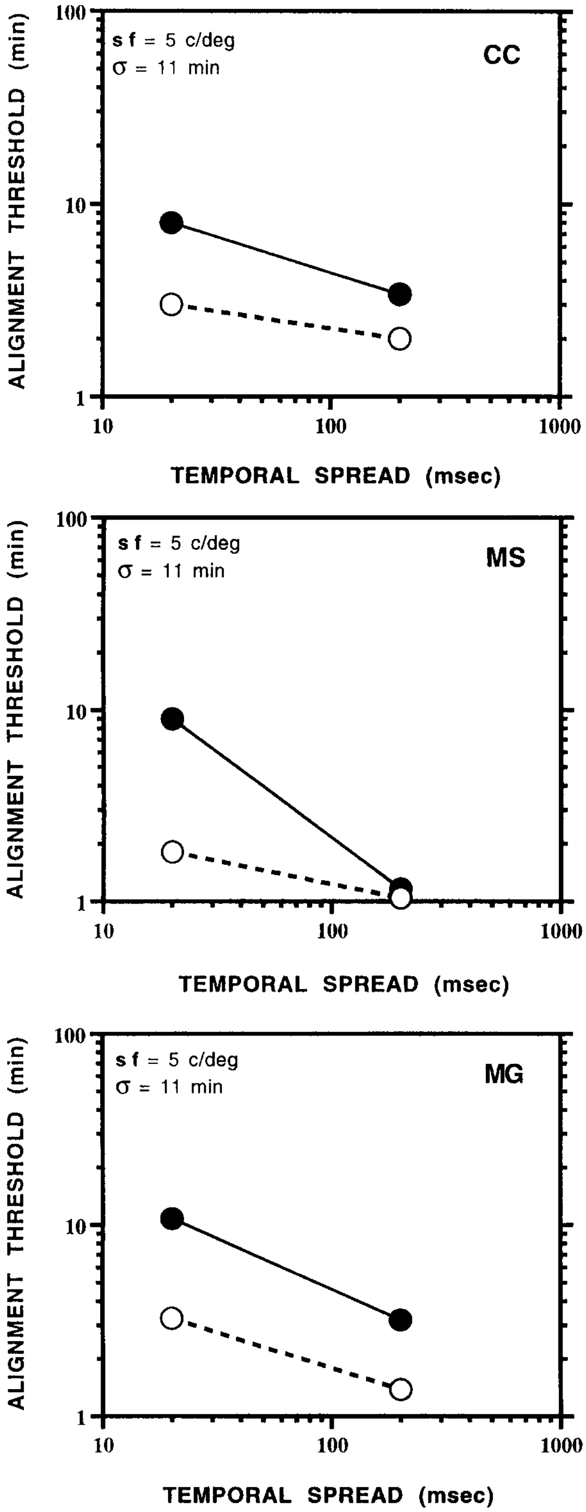

FIGURE 4. Alignment thresholds as a function of exposure duration, plotted as the spread of the Gaussian temporal envelope of the stimuli in msec, for the amblyopic (●) and fellow dominant eyes (○) of three strabismic subjects. The spatial properties of the stimuli, such as the spatial frequency of the carrier (sf) and standard deviation (σ) of the Gaussian *spatial* envelope are specified. In this case, stimulus elements are more closely spaced (2.5 × σ) and almost abutting. Error bars indicate the SEM and are at times smaller than the symbol sizes.

duration on alignment thresholds for three normal subjects for the stimulus separation of five times the standard deviation of the Gaussian spatial envelope (5 × σ). Exposure duration is plotted as the spread (1/e half width) of the Gaussian temporal window in msec. All subjects show an improvement in performance with increased presentation times, however, the dependence on exposure duration is weak. The slope of the averaged data for these three subjects is − 0.003 min/msec. Figure 2 compares the averaged data from the three normal subjects to that of the dominant eyes of the six amblyopic subjects. In general, a similar dependence on exposure duration is seen for the dominant eyes of amblyopes, although there is evidence for a raised level of spatial uncertainty in some of these eyes.

Figure 3 compares the amblyopic (■) and fellow dominant eyes (□) for all strabismic subjects tested. Generally the amblyopic eye's dependence on exposure duration is similar to that found for the dominant eye and for normal eyes (Fig. 2). There is however, in most cases, a raised level of spatial uncertainty compared to the dominant fellow eye.

Figure 4 shows similar data for three of our strabismic subjects at a stimulus spatial separation of 2.5 × σ. In one case (MS), there is clear evidence that the amblyopic eye's alignment threshold is substantially increased at the short duration condition and thus its performance is critically dependent on presentation time. This translates into the ratio of the positional deficit for stimuli which are almost abutting to be a factor of 4.4 worse for the short vs long presentation. This is much larger than that found for much wider spaced stimuli for this same subject, MS, shown in Fig. 3 (factor of 1.2). The other two subjects showed comparable performance for the short and long durations for closely spaced stimuli and as for more spatially separate stimuli, shown in Fig. 3, generally demonstrate that the positional deficit is invariant with exposure duration.

DISCUSSION

Our results suggest, in agreement with those of Hadani *et al.* (1984) and Waugh and Levi (1993), that there is at best a very weak dependence of spatial uncertainty on exposure duration when stimulus visibility is accounted for. Hadani *et al.* used spatially broadband stimuli and maintained equal energy at different exposure durations. Waugh and Levi measured vernier thresholds for abutting sinusoidal gratings, a task which is spatially broadband in the region where performance is assessed, and varied the contrast or exposure duration of the stimulus and found that the effect of exposure duration on vernier thresholds is almost completely accounted for by its effect on target visibility. We have taken the more direct but complementary approach of using spatially narrowband stimuli and setting them at a constant fraction above their individually measured contrast thresholds at different exposure durations so as to directly assess the effect that varying exposure duration has on alignment thresholds for equi-visible targets.

A similar dependence of alignment thresholds on exposure duration is seen in both the dominant and fellow amblyopic eyes in the majority of strabismic amblyopes.

They each show a raised level of spatial uncertainty but this varies minimally with exposure duration. Similar results were found for stimuli which were almost abutting. The dominant eyes perform worse than normal eyes and amblyopic eyes perform worse than their fellow dominant eyes. These results run contrary to the two claims of Rentschler and Hilz (1985) and Weiss *et al.* (1985). The first being that spatial uncertainty and phase discrimination in amblyopic eyes is critically dependent on exposure duration, the second being that the dominant eyes of amblyopes show "supranormal" positional sensitivity. Although in the Rentschler and Hilz (1985) study it was ascertained that all subjects could see the target with their amblyopic eye, the stimulation at the level of the early spatio-temporal filters was not rigorously equated in the amblyopic and fellow dominant eyes, as we have done here. This is our explanation for the dramatic difference between their results and ours. In the Weiss *et al.* (1985) study, there may have been an artifact introduced because of the restricted number of gray levels used to define the stimuli (Rentschler, personal communication).

Our finding of increased alignment thresholds in the dominant eyes of strabismic amblyopes while running counter to the claims made by Bradley and Freeman (1985) is in agreement with the results of Levi and Klein (1985). If the amblyopic positional loss is indeed due to uncalibrated neural disarray as proposed by Hess and Field (1994), then it is conceivable that the increased alignment threshold in the dominant eye may be a consequence of attempts to minimize spatial uncertainty in the amblyopic eye.

While it is true that spatial uncertainty in the majority of our subjects did not display a strong dependence on exposure duration for widely or closely spaced stimuli, it is clear from Fig. 4 that there are some strabismic subjects (e.g. MS) whose spatial uncertainty for closely spaced stimuli is critically dependent on exposure duration. This may provide a link between the current study and the previous study of Rentschler and Hilz (1985).

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